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RESEARCH IN PLANETARY STUDIES

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1. Introduction

This report covers the period January 1 to June 30, 1973, and covers primarily the planetary research activities of only two staff members - David Morrison and Robert E. Murphy - and of two graduate students - Andrew Lazarewicz and Terry Z. Martin. Staff member William M. Sinton was on sabbatical leave at the Jet Propulsion Laboratory throughout this report period, and staff member Dale P. Cruikshank left on February 21 for a six-month exchange visit to the U.S.S.R. During this period we completed some projects that were reported as in progress in our last semi-annual report, initiated some new ones, and continued working on some long-term programs that will continue into the next report period. From January 1 February 21, 1973 Cruikshank was responsible for the day-to-day administration and direction of this grant, and after February 21 these duties were assumed by Morrison.

2. Photometric Calibration at 11 and 20 Microns

In the past two semi-annual reports we have discussed our work to establish well-calibrated photometric systems at 11 and 20 microns that would permit us to measure accurate broad-band fluxes in these regions of the spectrum from both planetary and stellar sources. During this past 6 months, Morrison and T. Simon completed this work in the 20-micron band and have a paper in press in the Astrophysical Journal reporting photometry of 76 stars. Of these, 17 non-variable objects define the 20-micron magnitude system. They found 16 stars, all Miras, to be variable at this wavelength; observations of many of these are being continued in order to obtain accurate light curves at this wavelength, where much of the radiation arises in a relatively cool circumstellar

shell.

3. The Galilean Satellites

During this report period the extensive eclipse radiometry of the Galilean satellites by Morrison and Cruikshank was published, and Cruikshank and Murphy completed a report on their photoelectric photometry of the eclipses. As discussed in our previous report, Cruikshank and Murphy have taken advantage of the excellent observing conditions at Mauna Kea and of the newly constructed double-beam photometer on the 61-cm telescope to show clearly that the post-eclipse brightening on Io, in dispute for years, is real but intermittent. The best explanation still seems to be that this brightening is due to partial condensation of a tenuous atmosphere during eclipse, followed by its sublimation after reappearance.

In a paper written while he was at Jet Propulsion Laboratory (and now in press in Icarus), Sinton has suggested an explanation of this post-eclipse brightening, and of other anomalous behavior of Io, in terms of an atmosphere on the satellite that varies in pressure with season, being largely frozen out at the poles of Io except near the equinoxes. He further suggests that the high flux of protons from the Jovian radiation belt heats this atmosphere substantially. Sinton and Murphy will search for direct evidence of this atmosphere this summer by observing Io in narrow bands in the 10-micron region that isolate the emission lines expected from Sinton's analysis.

Morrison is continuing his work on the rotational variations of brightness of the Galilean satellites in the visible and in the infrared. In collaboration with graduate students Lazarewicz and N. D. Morrison, he has obtained uvby photometry that gives good coverage of Io, Europa, and Ganymede for one or more complete revolutions. These data will be analyzed together with the

10- and 20-micron radiometry obtained in 1971, 1972, and 1973.

Murphy has begun a new program to study the Galilean satellites through photometry of the mutual eclipses and occultations of these objects that take place primarily during the second half of 1973. Observations of the first two events visible from Mauna Kea, occultations of Europa by Io on 17 June and 24 June 1973, showed that the loss of light was respectively 80% and 55% greater than predicted, while the durations and absolute times of the events were exactly in accord with predictions. These data present strong evidence for a polar cap on Europa, as discussed in a note submitted to Nature.

4. Jupiter

Murphy and graduate student R. Fesen have continued their analysis of the 20-micron scans of Jupiter. The equatorial hot zone noted before has an excess temperature of 3°K, rather than the 6°K figure mentioned in the previous report. The excess flux may originate entirely within the NEB and SEB rather than in the entire equatorial region; our spatial resolution is inadequate to determine such fine structure. In addition the STeB was found to be warmer than the adjacent regions. All three hot zones coincide with grey clouds which have been noted by Westphal to be the type locality for 5-micron hot spots. Keay and Low have found these same regions to be hot at 5 microns in a series of more or less contemporary measurements. It is likely that the 5-micron hot spots, which originate deep in the atmosphere, the 20-micron hot zones, which originate high in the atmosphere, and the grey clouds (or non-clouds), are interrelated. Murphy and Fesen find a 17- to 28-micron

brightness temperature at the center of Jupiter's disk of $136 \pm 3.5^\circ\text{K}$. This corresponds to an effective temperature $T_e = 142 \pm 3.5^\circ\text{K}$ at the center of the disk. Allowing for limb darkening and the spatial variations noted above, they find $T_e = 136 \pm 3.5^\circ\text{K}$ for the entire disk. They also note that there is no detectable difference between the temperature of the Red Spot and the neighboring regions to within 1°K . These results have recently been submitted to Icarus for publication.

5. Saturn and Its Rings

Murphy, in collaboration with J. C. Kemp, has measured the linear polarization of Saturn's rings at various wavelengths from 3700 \AA to 1.7 microns, as well as selected regions of A and B rings at 7000 \AA . The direction was uniformly "negative"; the electric vector was parallel to the solar-system plane to within $\pm 7^\circ$ at all wavelengths and positions studied, except for an uncertainty of $\pm 20^\circ$ at two infrared points. The polarization showed a minimum of 0.25% near 7000 \AA , a rise of 0.60% at 3700 \AA in the near u.v., and a rise to over 0.60% in the infrared (1.7 microns). The measured polarization of the portion of the B ring which occults the North Pole was found to be reduced due to the admixture of positively-polarized disc light which has been transmitted through the ring. Observation of the latter effect at 7000 \AA under optimum seeing conditions yields the first actual measurement of the optical transmittance of the B rings, namely (21 ± 6) percent, corresponding to $\tau = 0.7$. This is consistent with Murphy's 20-micron studies of the rings (discussed in our previous report and recently published in The Astrophysical Journal Letters) which implied $\tau = 0.7$, if Cook, Franklin, and Paluconi's albedos for the ring particles are correct. The polarization work is now in press in The Astrophysical Journal.

Morrison has made further observations of the rings and disk of Saturn at 10 and 20 microns, primarily in order to determine the distribution of temperature around the rings. He finds that the drop in the brightness temperature of the rings observed 5 ± 1 arcsec after emergence from the shadow of the planet is 1.5°K , with an upper limit of 3°K . When analyzed in terms of the models recently computed by Aumann and Kieffer, these results suggest particle size of about 2 cm or larger. Additional data on the temperatures of the rings and disk are not yet fully reduced and will be discussed in the next semi-annual report.

6. Satellites of Saturn

Morrison, Cruikshank, and Lazarewicz, in collaboration with M. Nolan, J. Veverka, J. Elliot, and J. Burns of Cornell University, completed extensive 6-color photometry of Iapetus, Titan, Rhea, Dione, and Tethys. These data have been reduced, and they permit us to determine magnitudes, colors, phase coefficients, and rotational light curves for these objects. We are now working on the interpretation of the results, which will be discussed in the next report. Morrison has also made further 20-micron observations of Iapetus, Rhea, and Dione, and he has in preparation a paper discussing the albedos and radii of the inner satellites of Saturn.

7. Uranus, Neptune, Pluto, and Triton

Murphy and L. Trafton of The University of Texas are preparing a paper that compares Morrison and Cruikshank's infrared measurements of Uranus and Neptune to model calculations. They show that, when revisions in the telluric water vapor abundance are taken into account, the Uranus observations are matched by a model with $T_e = 60^\circ\text{K}$ with $\text{He}/\text{H}_2 = 1$. The Neptune data are

inconsistent with any reasonable model cooler than 55°K. Thus Uranus appears to be in equilibrium with the insolation, while Neptune must, like Jupiter and Saturn, possess an appreciable source of internal energy.

Martin has obtained four photographic spectra of Triton and three of Pluto at a dispersion of 50 Å/mm near the methane band at 6190 Å. He used an RCA image intensifier with the Cassegrain spectrograph at Mauna Kea Observatory. No evidence was found for absorption due to methane on either body. Although the data are still being reduced, they are expected to yield a much better upper limit on the methane abundance above the surfaces of Pluto and Triton.

8. Asteroids

Morrison has continued the 10- and 20-micron radiometry of asteroids begun by him and Cruikshank last year. During this report period, two papers by Morrison discussing the method of deriving albedos and radii of satellites and asteroids were published, and a paper by Cruikshank and Morrison presenting results for 9 asteroids has been submitted to Icarus. About 20 new asteroids have been observed this year, and within the next few months Morrison expects to be able, by combining his data with that already in the literature, to present an analysis of as many as 50 asteroids. This work is being coordinated with spectrophotometry by C. Chapman and polarimetry by B. Zellner of many of these same objects. A semi-popular article on modern studies of asteroids by Chapman and Morrison has been submitted to Sky and Telescope.

9. The New 35-Micron Spectral Region

Murphy, working with I. G. Nolt and J. V. Radostitz of the University of Oregon, has measured the brightness temperature of Saturn at a mean wavelength of 35 microns using a system developed by the Oregon group. They find the

results are in agreement with Trafton's model atmospheres. The 28- to 43-micron brightness temperature is 104°K , corresponding to an effective temperature of 110°K . This effective temperature is higher than is generally assumed, but it is in agreement with the 17- to 28-micron measurement recently published by Murphy, which implies $T_e = 108^{\circ}\text{K}$; these results have been submitted to The Astrophysical Journal.

The 35-micron window is more weather-sensitive than is the 20-micron window, and further observations were hindered in late spring by an unusually wet spell ($\sim 2 \text{ mm H}_2\text{O}$). Nolt, Radostitz, and Murphy were, however, able to establish signal levels for several additional objects even though the window transmission dropped to less than 2%. In addition they obtained interferometric spectra of the sky emission. Concurrent or nearly concurrent sky spectra are necessary in order to evaluate properly the system bandpass, which depends heavily on the telluric spectrum. The spectra have been compared to the synthetic spectra of V. Kunde and found to be in good agreement. Murphy and Sinton, together with Nolt and Radostitz, anticipate continuing observations in this window, which represents the longest infrared wavelengths observable from ground-based sites until one reaches the submillimeter region at 350 microns.

10. Fourier-Transform Interferometry

The Institute's Block-Digilab FTS system has been used for the first time during this report period on the 2.24-meter telescope. Graduate students Martin and N. D. Morrison have assumed primary responsibility for the system from the time of Cruikshank's departure to the end of this report period. At Mauna Kea, spectra of the Moon and a few bright stars were obtained with

resolutions as high as 2 cm^{-1} . These spectra demonstrate that at Mauna Kea valuable spectroscopy can be performed in the 1.9-micron H_2O band, which is saturated at most other sites. An attempt to observe Saturn at 8 cm^{-1} resolution in the 1- to 3-micron band was not successful, due to a defective beam splitter and to malfunctions in the data system.

Although we have obtained spectra of bright sources with this system on the telescope, the spectrometer is not yet routinely capable of obtaining spectra of the fainter objects in which we are primarily interested. It has become obvious that the computer hardware that controls the functioning of the interferometer and processes the data is too unreliable to be used for observing on Mauna Kea. Even though the equipment worked properly in the laboratory, it has failed during each observing run but one on Mauna Kea, and each failure has required a visit by a repairman before the spectrometer could be used again. Each failure has been different, but we surmise that the tendency to fail is caused by the high altitude. One effect of low air pressure could be that some temperature-sensitive components are inefficiently cooled, and we are experimenting with fans to aid cooling. Another possibility is that the disk, which is implicated in the two most recent failures, may need to be sealed in a pressurized chamber.

A long-standing problem is the failure of the sky-compensation system to function. According to the manufacturer, the difficulty is that the coating of the originally supplied beam splitter is not the pure dielectric, iron oxide, but contains a significant amount of metallic iron. Block is now reworking the coating. We have also had difficulty with the sensitivity of the InAs detector. Block has informed us that the performance of this detector, which operates from 1.2 to 3 microns, can be improved upon, and we are taking

steps to have this detector replaced. In addition, we have established an improved method for establishing the crucial alignment required if the interferometer is to operate successfully.

We estimate that an increase of roughly a factor of 10 in sensitivity will allow the instrument to yield useful data and to compete with such other Fourier spectrometers as the half-wavenumber Block interferometer at Arizona. Among the approaches outlined in the preceding paragraphs, we think that we can achieve such an increase. The FTS system is scheduled for use at Mauna Kea again in August.

11. Other Topics

Morrison and Cruikshank are continuing work on their major review paper on the physical properties of the natural satellites, to be submitted to Space Science Reviews in October. Morrison also presented an invited review paper on asteroids and satellites at the March annual meeting of the AAS Division for Planetary Sciences.

Morrison, Murphy, and Sinton all attended the AAS/DPS meeting in Tucson and presented a total of 6 contributed papers.

A paper on the qualities of Mauna Kea as an observatory site, by Morrison, Murphy, Cruikshank, Sinton, and Martin, is to be published in the June 1973 issue of P.A.S.P. We are continuing to keep detailed records at the site, and these will be supplemented this summer by site studies being made at Mauna Kea by French and British astronomers.

LIST OF PUBLICATIONS, NOT INCLUDING ABSTRACTS, OF THE INSTITUTE FOR ASTRONOMY
PLANETARY GROUP FOR THE PERIOD JANUARY 1 - JUNE 31, 1973.

I. PAPERS PUBLISHED

Cruikshank, D. P. 1972, "The 3rd Annual Meeting of the AAS Division for
Planetary Sciences," Icarus, 17, 714.

Morrison, D. 1973, "New Techniques for Determining Sizes of Satellites and
Asteroids," Comments on Astrophys. and Space Physics, 5, 51.

Morrison, D., and Cruikshank, D. P. 1973, "Thermal Properties of the Galilean
Satellites," Icarus, 18, 224.

Morrison, D., and Cruikshank, D. P. 1973, "Temperatures of Uranus and Neptune
at 24 Microns," Ap. J., 179, 329.

Murphy, R. E. 1973, "Temperatures of Saturn's Rings," Ap. J. (Lett.), 181, L87.

II. PAPERS IN PRESS

Cruikshank, D. P., Hartmann, W. K., and Wood, C. A. 1973, "Moon: 'Ghost'
Craters Formed During the Mare Filling," The Moon.

Cruikshank, D. P., Morrison, D., and Lennon, K. 1973, "Volcanic Gas: Hydrogen
Burning at Kilauea Volcano," Science.

Cruikshank, D. P., and Murphy, R. E. 1973, "The Post-Eclipse Brightening of Io,"
Icarus.

Kemp, J. C., and Murphy, R. E. 1973, "The Linear Polarization and Transparency
of Saturn's Rings," Ap. J.

Morrison, D. 1973, "Determination of Albedos and Radii of Satellites and
Asteroids from Radiometry and Photometry," Icarus.

II. PAPERS IN PRESS (continued)

Morrison, D., Murphy, R. E., Cruikshank, D. P., Sinton, W. M., and

Martin, T. Z. 1973, "Evaluation of Mauna Kea, Hawaii, as an Observatory Site," P.A.S.P.

Morrison, D. and Simon, T. 1973, "Broad-Band 20-Micron Photometry of 76 Stars," Ap. J.

Sinton, W. M. 1973, "Does Io Have an Ammonia Atmosphere?" Icarus.

III. PAPERS SUBMITTED

Cruikshank, D. P., and Morrison, D. 1973, "Radii and Albedos of Asteroids 1, 2, 3, 4, 6, 15, 51, 433, and 511," Icarus.

Chapman, Clark R., and Morrison, David 1973, "Modern Studies of Asteroids," Sky and Telescope.

Murphy, Robert E., and Aksne, K. 1973, "A Polar Cap on Europa," Nature.

Murphy, Robert E., and Fesen, Robert A. 1973, "Spatial Variations in the Jovian 20-Micron Flux," Icarus.

Nolt, I. G., Murphy, R. E., Ford, H. C., Radostitz, J. V., Lester, D. F., and Donnelly, R. J. 1973, "Ground-Based Observations of Saturn's Rings and Disk at 35-Microns," Ap. J.

IV. PAPERS IN PREPARATION (final titles may differ slightly)

Cruikshank, D. P., "The Size and Albedo of the Trojan Asteroid 624 Hektor."

Morrison, D., "Radiometry of the Inner Satellites and Rings of Saturn."

Morrison, D., "Rotational Variations of the Galilean Satellites. II. Photometry at 10 and 20 Microns."

Morrison, D., and Cruikshank, D. P., "Physical Properties of the Natural Satellites."

IV. PAPERS IN PREPARATION (continued)

Morrison, D., Lazarewicz, A., and Morrison, N. D., "Rotational Variations of the Galilean Satellites. I. uvby Photometry."

Murphy, R. E., "The 20-Micron Infrared Emission of Saturn's Rings and the Variation of Their Temperature with Time."

Murphy, R. E., and Trafton, L. M., "The Internal Heat Source of Neptune."

Nolan, M., Veverka, J., Morrison, D., Cruikshank, D. P., Lazarewicz, A., Elliot, J., and Burns, J., "Six-color Photometry of the Satellites of Saturn."

Sinton, W. M., and Carson, R., "Water Vapor Studies of Mars at the Opposition of 1971."